Air Transportation System: Challenges and Opportunities

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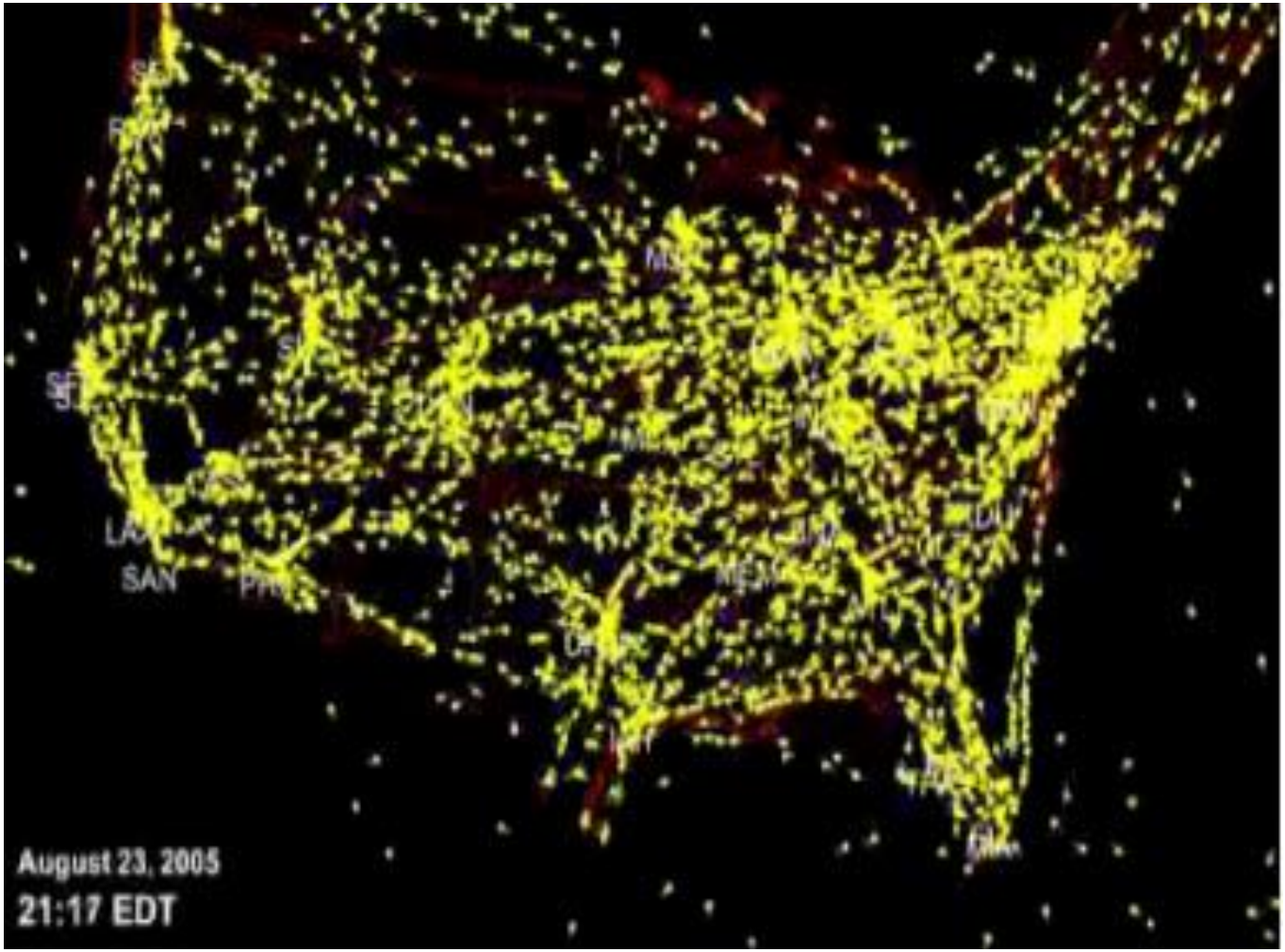
Outline

- National Airspace System
- Operational Challenges
- Research and development areas and NASA products
- Autonomy Opportunities
- Summary

Global Air Traffic

24 Hours in the airspace over the globe

National Airspace System



A day in the National Airspace System

National Airspace System

- $1.3T to US economy, $636B spent by travelers
- 3.6B passengers worldwide in 2018
- 800 million passengers/year
- 50,000 flights operations
- 14,500 air traffic controllers
- 4,500 aviation safety inspectors
- 5,800 technicians to operate and maintain
- More than 19,000 airports and 600 air traffic control facilities.
- In all, there are 41,000 NAS operational facilities
- Over 71,000 pieces of equipment
- FAA spends about $7B to manage air traffic operations

The NAS is a highly complex system

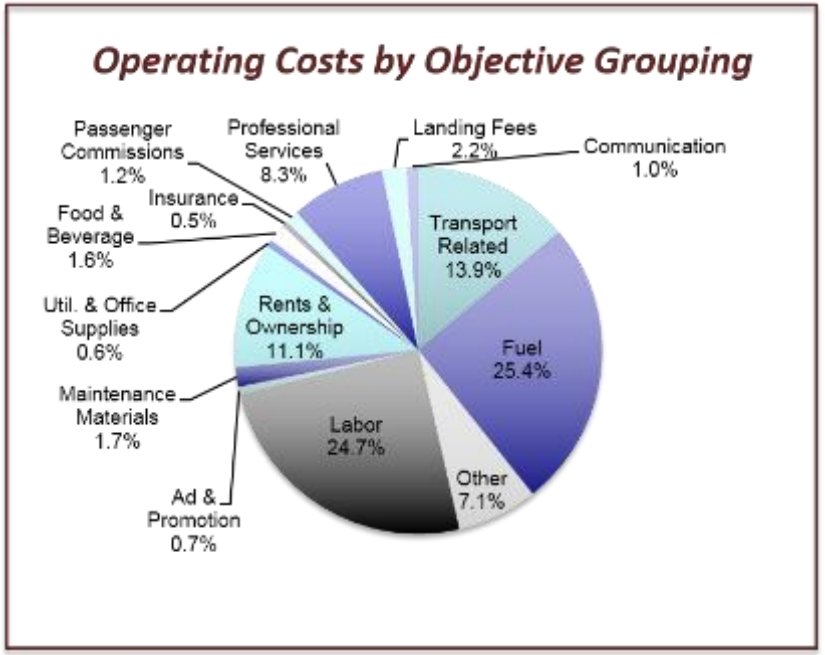
Air Transportation System Needs

- Operators
  - On-time performance, predictability, fuel efficiency, growth, and cost
- Service Providers
  - System performance, productivity, capacity, scalability and cost
- National and community needs
  - Competitiveness, safety, and environmental impact
- Passengers
  - On time performance, mobility, and affordability

Multiple needs of the air transportation system

Current Aviation Business Environment

- Airline costs: 25% each fuel and labor
- Fuel prices remain volatile
- Stiff competition in international market
- Financial survivability remains a challenge
- Horizontal and vertical integration trend continues (e.g., Delta purchasing refinery)
- Current focus of research and development – increasing efficiency
- Longer-term focus - reduce total cost, allow diverse use of airspace, increase mobility



Fuel and labor costs put pressure on competitiveness

State of the Art

- Role of air traffic management is to maintain safe, expeditious, and efficient flow of traffic
  - Strategic decisions (2-6 hours in advance)
    - National Airspace System and facility flow strategies in and out of all airports and airspace in presence of weather and demand/capacity imbalance
  - Operations at each airport (Tower, 2-5 miles from airport)
    - Movement of aircraft on taxiways and runways, and arrivals/departures near airport
    - Set runway configuration (arrival/departure allocation)
  - Operations near airport (Terminal, 30-50 miles from airport)
    - Keep aircraft separated and balance arrival/departure flows
    - Provide efficient routings for arrivals, departures, and over flights
  - Operations in airspace (En route and oceanic, rest of airspace)
    - Keep aircraft safely separated from each other and avoid severe weather
    - Provide most efficient operations

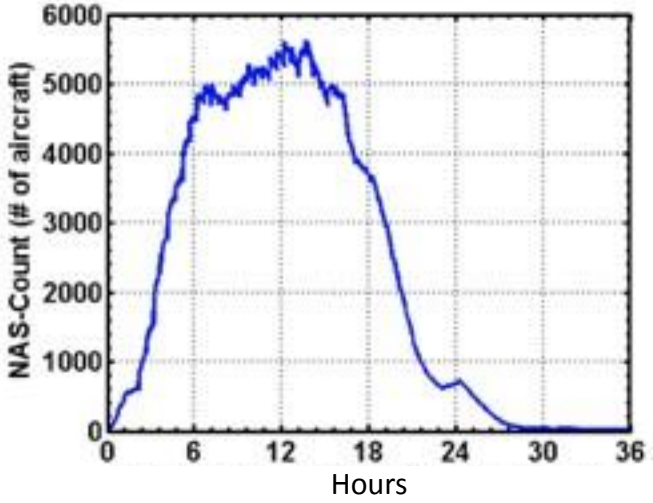
Current system is manual, and limits scalability

Statistics Per Flight

	Time (minutes)	Distance (Nautical-miles)	Fuel Burnt (lbs)
Surface	19	5	474
Climb	16	76	1,911
Cruise	70	465	6,787
Descent	14	68	349

	Min. Time (minutes)	Max. Time (minutes)	Min. Fuel Burnt (lbs)	Max. Fuel Burnt (lbs)
Surface	11	43	274	1,073
Climb	5	56	520	18,704
Cruise	0	1,039	0	375,350
Descent	4	40	175	1,942

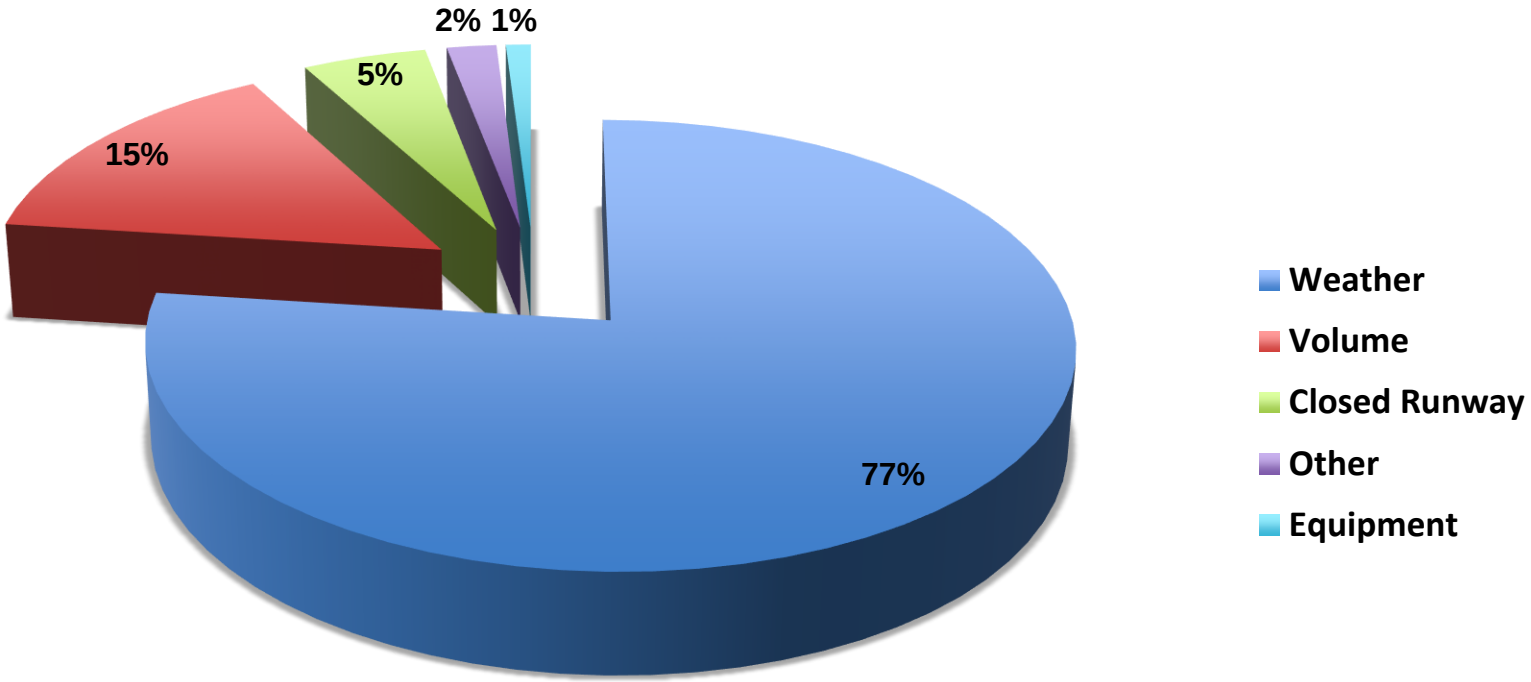
	CO_2 (lbs)	H_2O (lbs)	SO_X (lbs)	NO_X (lbs)	CO (lbs)	HC (lbs)
Surface	1,659	650	0.5	7	1.6	0.2
Climb	6,698	2,626	2.1	28	6.4	0.6
Cruise	23,781	9,324	7.5	98	22.6	2.3
Descent	1,223	480	0.4	5	1.2	0.1



- 24-hours from 8:00 UTC May 3 to 8:00 UTC May 4, 2007.
- High-volume, low-delay day, 56,267 flights (71% jets, 17% turboprops,12% piston).

National Airspace System Delays

25% of aircraft get delayed, 77% of those due to weather



Weather is a big delay contributor

Air Navigation Services

- Flow management strategies
- Dynamic airspace adjustments
- Surface movement strategies
- Sequencing and spacing
- Efficient arrival and departure operations
- Conflict prediction, detection and resolution

Services need to be efficient and effective

Barriers…to meeting air transportation system needs

- Human workload
- Limited automation
- Lack of up-to-date information

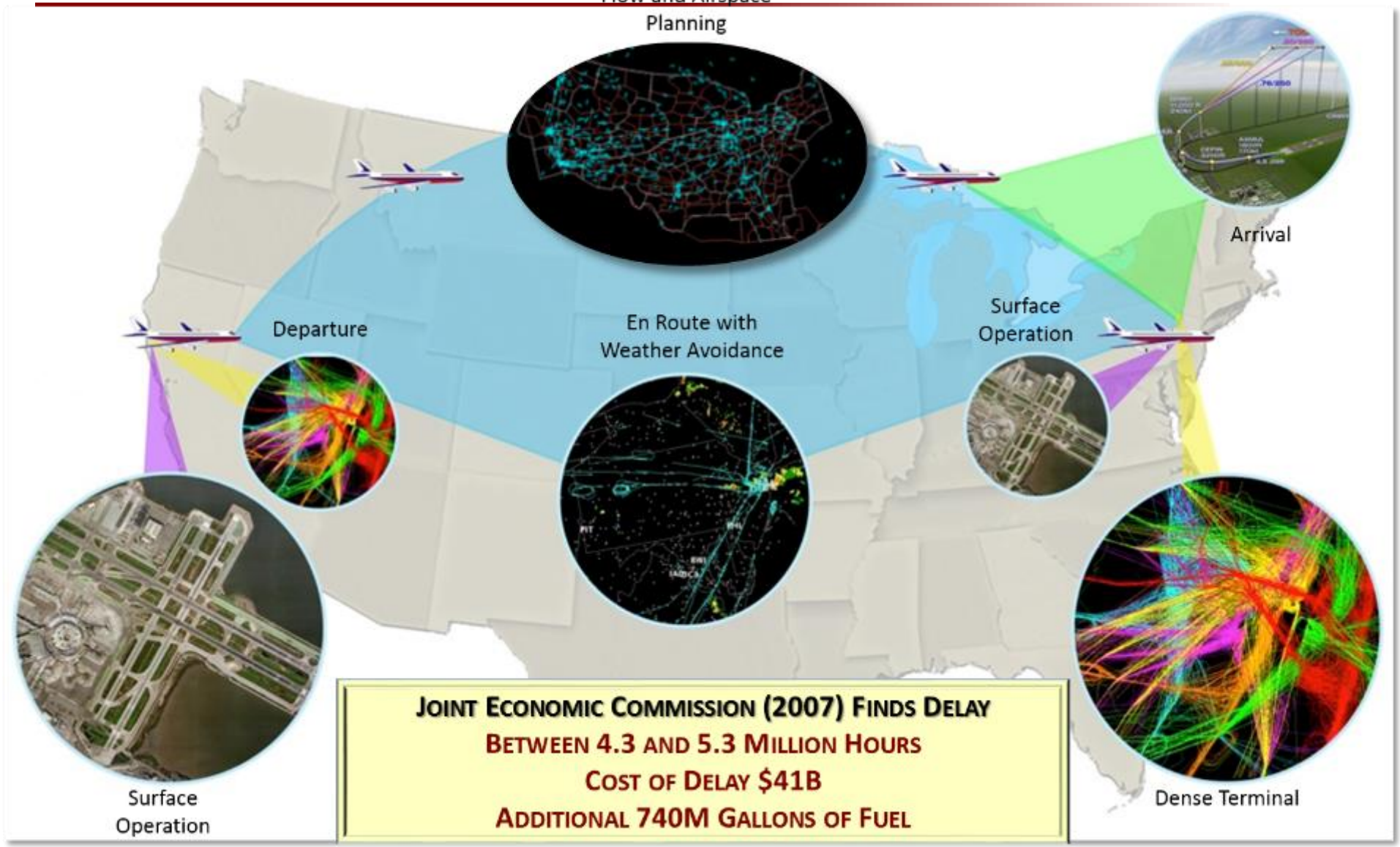
Limited automation leads to sub-optimal performance

NASA's Research Goals

- Scalable system that is aimed to accommodate future traffic demand, variety, and mobility needs
- Develop and validate concepts, algorithms, and technologies based on analysis, simulations, and field tests
- Combination of flight deck and ground-based concepts and technologies
- Integrated trajectory-based solutions to maximize efficiency of all phases of flight

Develop and validate ground-based and airborne concepts and technologies

Gate-to-Gate Concepts and Technology



Current system is inefficient

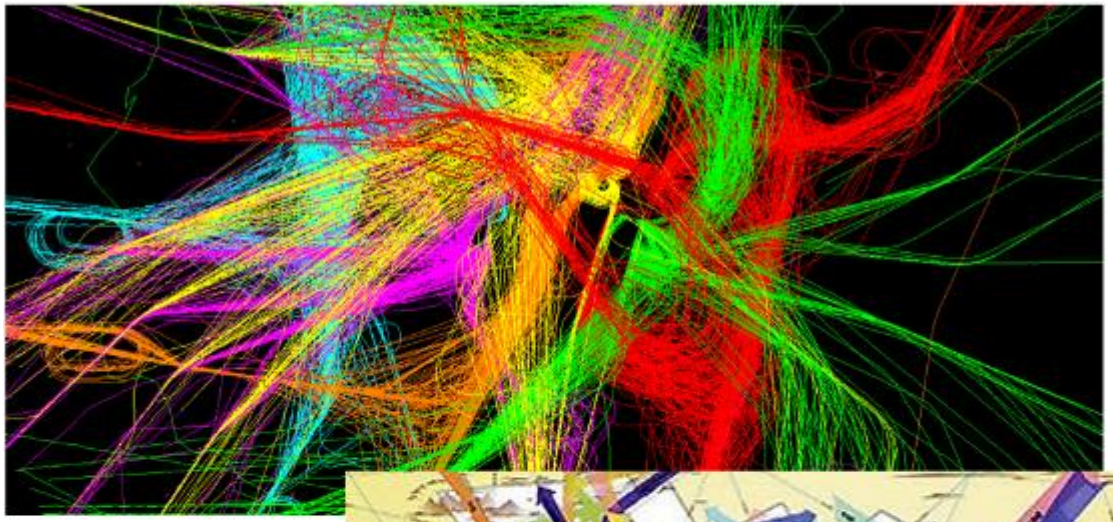
Major Research and Development Areas

- Integrated Arrival/Departure/Surface Operations
- Weather Integrated Decision Making
- Separation Assurance/Functional Allocation
- Oceanic Operations Efficiency Improvement
- Large-scale simulation capability: Shadow Mode Assessment for Realistic Technologies for the National Airspace
- Trajectory-based Operations
- Networked Air Traffic Management
- Autonomy: AutoMax

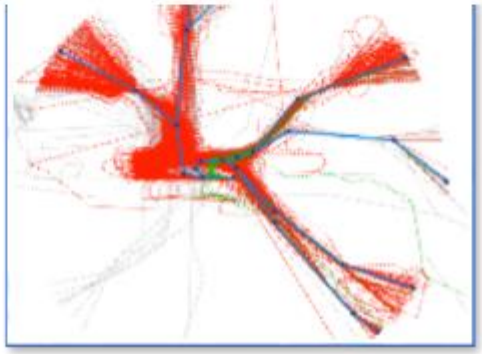
Research and development areas address major NAS operational needs

Integrated Arrival/Departure/Surface Operations

Simultaneously increase arrivals, departures, and surface operations efficiency while increasing overall throughput

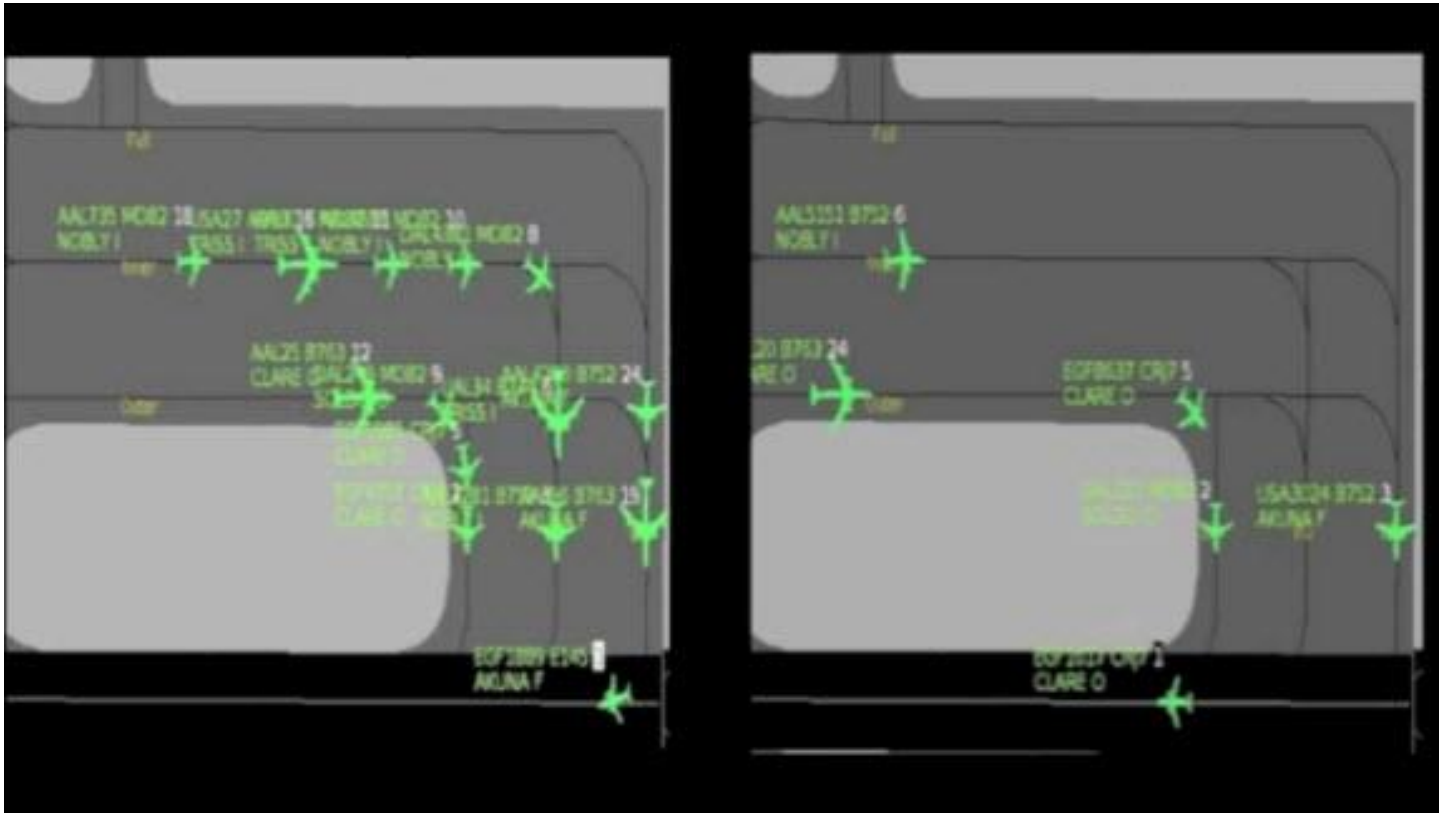


"I saved 10 minutes at the hotel with speedy checkout, 10 minutes at the car rental with instant check in. Now I'm spending 6 hours on the runway."



Simultaneously increase throughput and individual aircraft efficiency

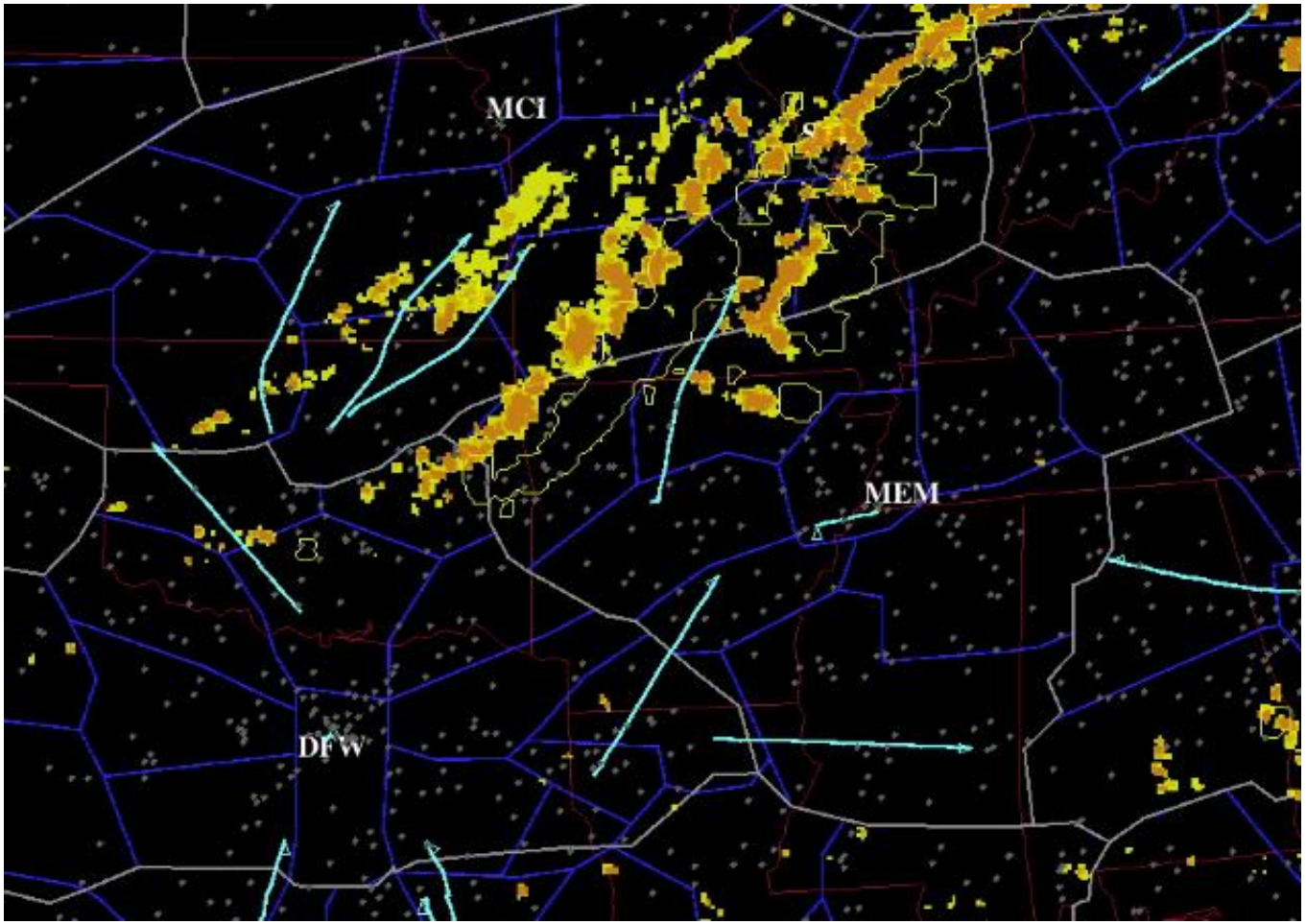
Efficient Surface Movement



Spot and Runway Departure Advisor

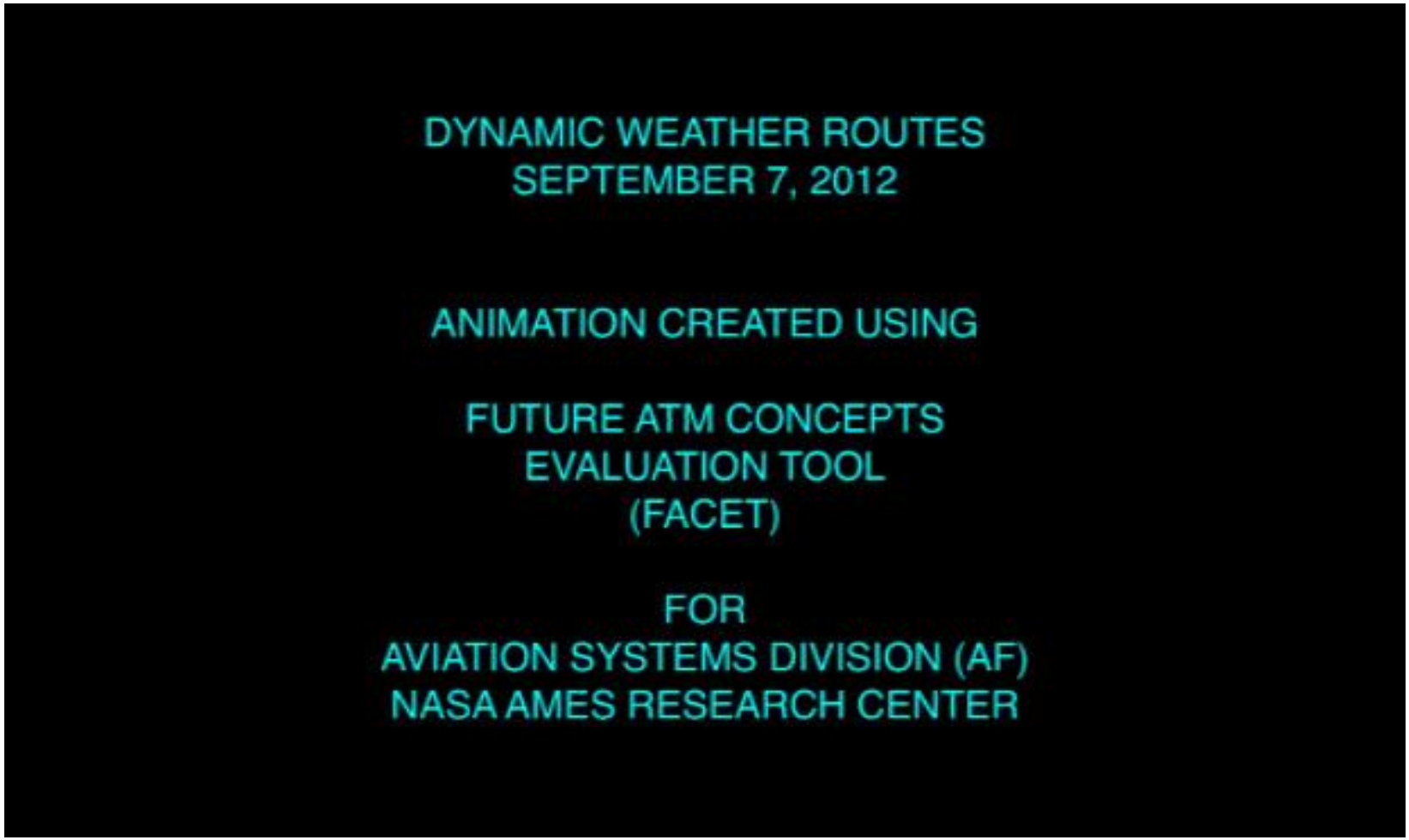
Weather Integrated Decision Making

Reduce weather-induced delays by integrating probabilistic weather information



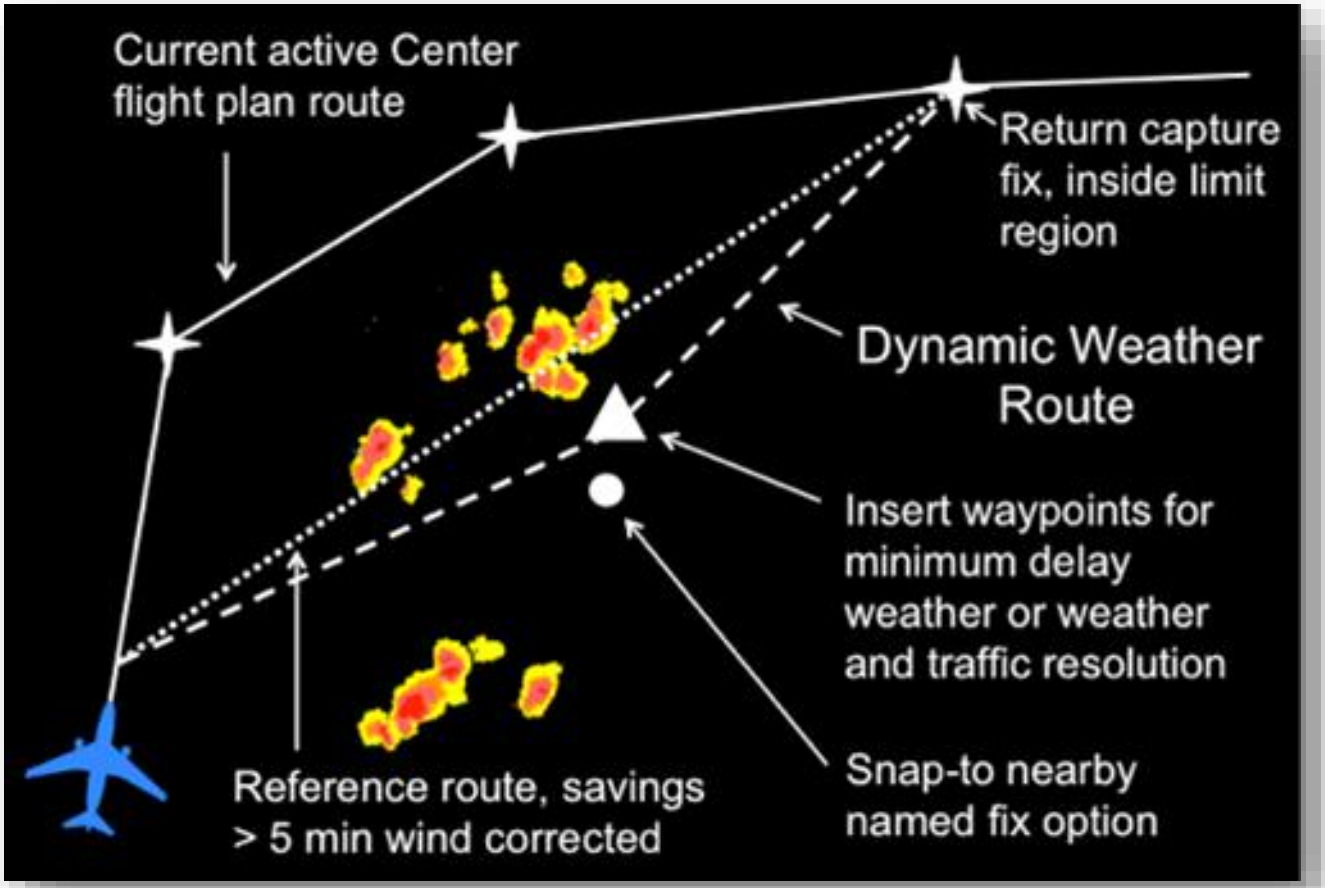
Weather contributes to 75% of delays and costs $10B

Weather Integrated Decision Making

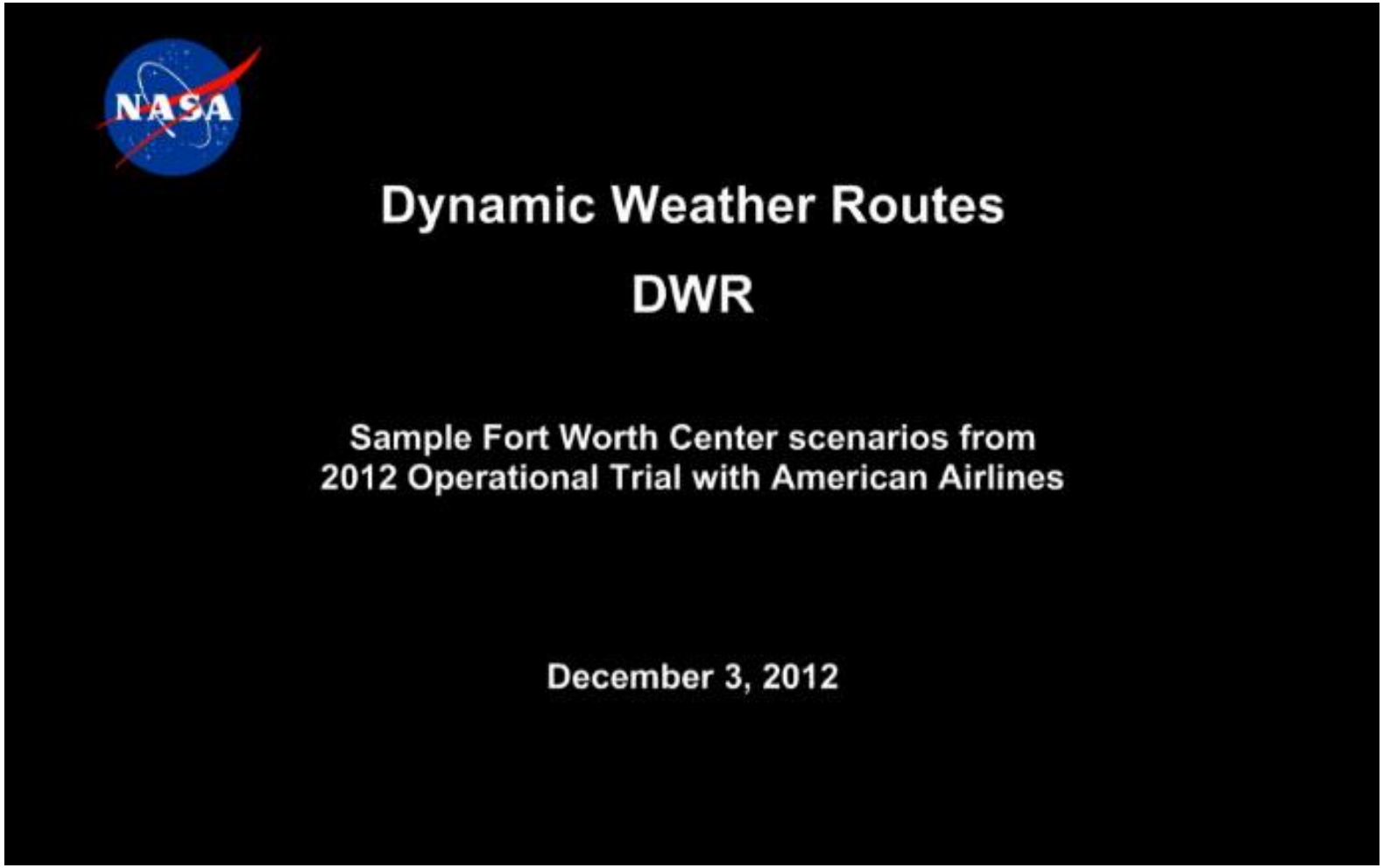


Dynamic Weather Routes

Develop dispatcher decision support tool that will provide dynamic, efficient routing for airborne aircraft and flows to avoid severe weather at regional level



Dynamic Weather Routes (DWR)



Successful American Airlines operational trials

Traffic Aware Strategic Aircrew Requests

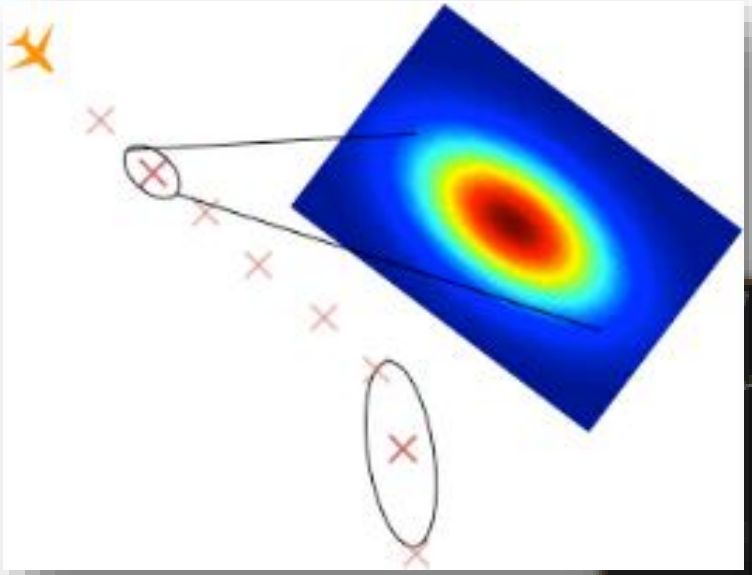
Develop aircraft-based technology to support flight-optimizing user requests that are approvable by air traffic controllers

A Piaggio P.180 Avanti owned and operated by AdvAero was used for the TASAR flight test.

The touch screen of the Electronic Flight Bag allows pilots to easily use NASA's Traffic Aware Strategic Aircrew Requests (TASAR) software.

Separation Assurance and Functional Allocation

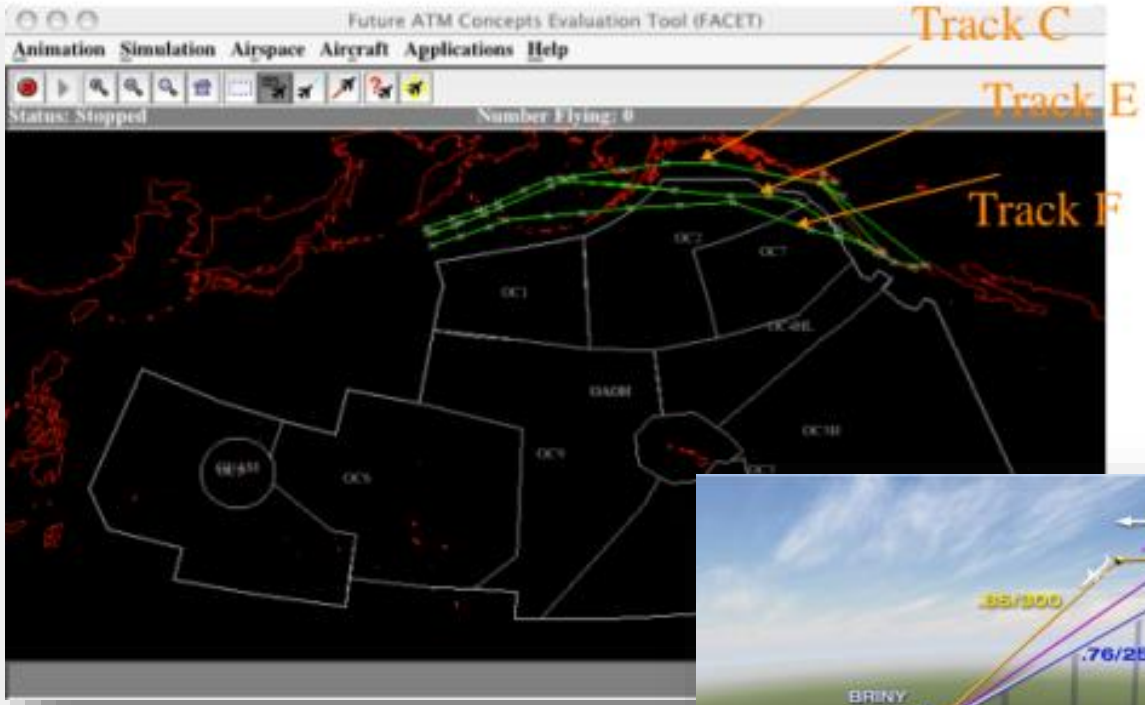
Establish the basis for air/ground functional allocation for separation assurance including safe, graceful degradation of performance in response to off-nominal conditions

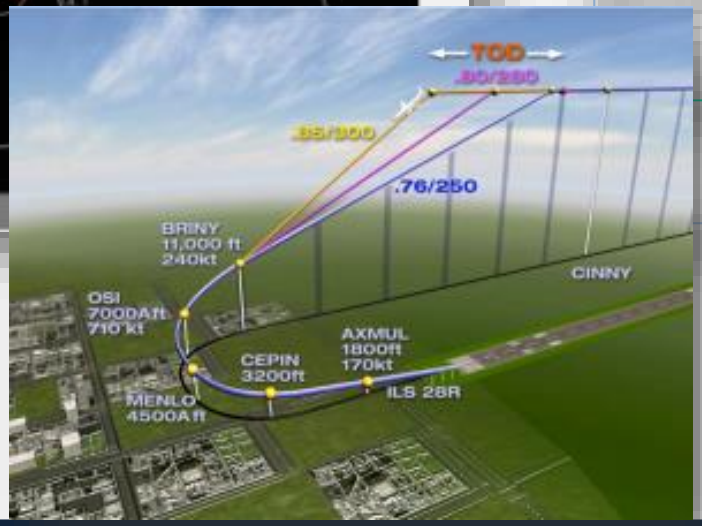


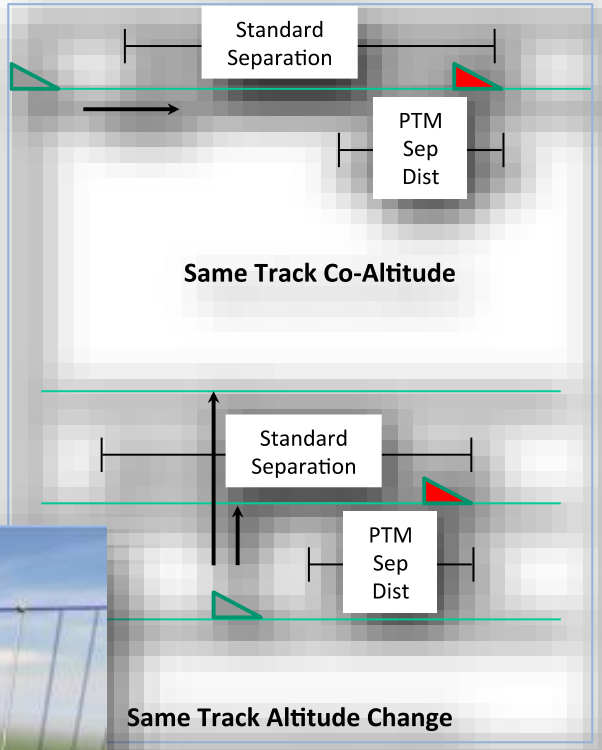
Close to 100% detection and resolution performance is required

Oceanic Operations Efficiency Improvement

Increase oceanic airspace operational efficiency by efficient routing based on changes in weather, and reduced separation minima based on ADS-B







Number of technologies available to increase efficiency in oceanic airspace

Enabling Trajectory-based Operations

Increase efficiency of flights by enabling trajectory-based operations rather than airspace-based operations and reducing delay-increasing tactical changes to trajectories

End-to-end Trajectory-based Operations

Networked Air Traffic Management

Develop and demonstrate concepts, algorithms, technologies, architectures, and business models employing advanced networking capability that will significantly reduce cost by reducing duplication of data, processing, and information

Networked ATM to reduce duplication, increase productivity, and reduce costs

AutoMax: Towards Autonomy

- Increase **mobility** of passengers, goods, and services
- Allow **diverse** vehicle mix and airspace uses (e.g., air travel, wind turbines, commercial space launches)
- Enable **scalability** to accommodate future demand
- Accommodate a variety of **business models** (e.g., hub-and-spoke, point-to-point, air taxi, sharing, etc.)
- Maintain highly efficient, predictable, agile, scalable, and **affordable** airspace operations system
- Maintain global **competitiveness** and domestic viability by innovation in technology and business models to manage airspace operations

Accommodate future mobility, diversity, business models with scalable and sustainable operations

Examples of *Auto* Properties for Airspace Operations

- Autonomicity: system focused self-management, technologies for
  - ***Self-configuration*:** Capacity-to-safety transition in operations
  - ***Self-optimization***: Optimization based on changing conditions in traffic, weather, and disruptions
  - ***Self-protection***: Anomaly detection (e.g., GPS degradation) and reaction
  - ***Self-healing*:** Recovery from degradation
- Autonomous operations and autonomy technologies for
  - Non-towered airports, flow management, unmanned vehicles, personal and passenger air vehicles
- Automation Technologies
  - Conflict detection and resolution, route planning, severe weather avoidance, reduced crew operations, remotely operated vehicles

Increased “auto” automation, autonomy, and autonomicity are needed to meet future needs

Need for *Auto* characteristics in Airspace Operations System – Safety, Efficiency/Scalability, Mobility

- **Human simply executes automation guidance where rapid decisions and execution is needed –** Traffic Collision Avoidance System (TCAS)
- **Rare normal events may lead to human skill degradation** – Aircraft stall management
- **High complexity leads to suboptimal human decision making –** safe, expeditious, and efficient operations
  - Probabilistic weather, multiple constraints *(too much information for humans to make sound decisions)*
- **High workload limits capacity and throughput –** Human workload limits number of aircraft
- **Human-centric system costs limit mobility –** Air taxi/On-demand aircraft with two pilots or personal air vehicles requiring piloting skills
- **Labor cost differences impact competitiveness** – Huge cost difference in global economy
- **Enable new operations with high productivity** – Low altitude UAS operations

Need for auto enablers due to complexity, diversity, demand, costs pressures, and newer needs

Single Pilot Operations

Examine if reduced crew operations are feasible

Single Pilot Operations

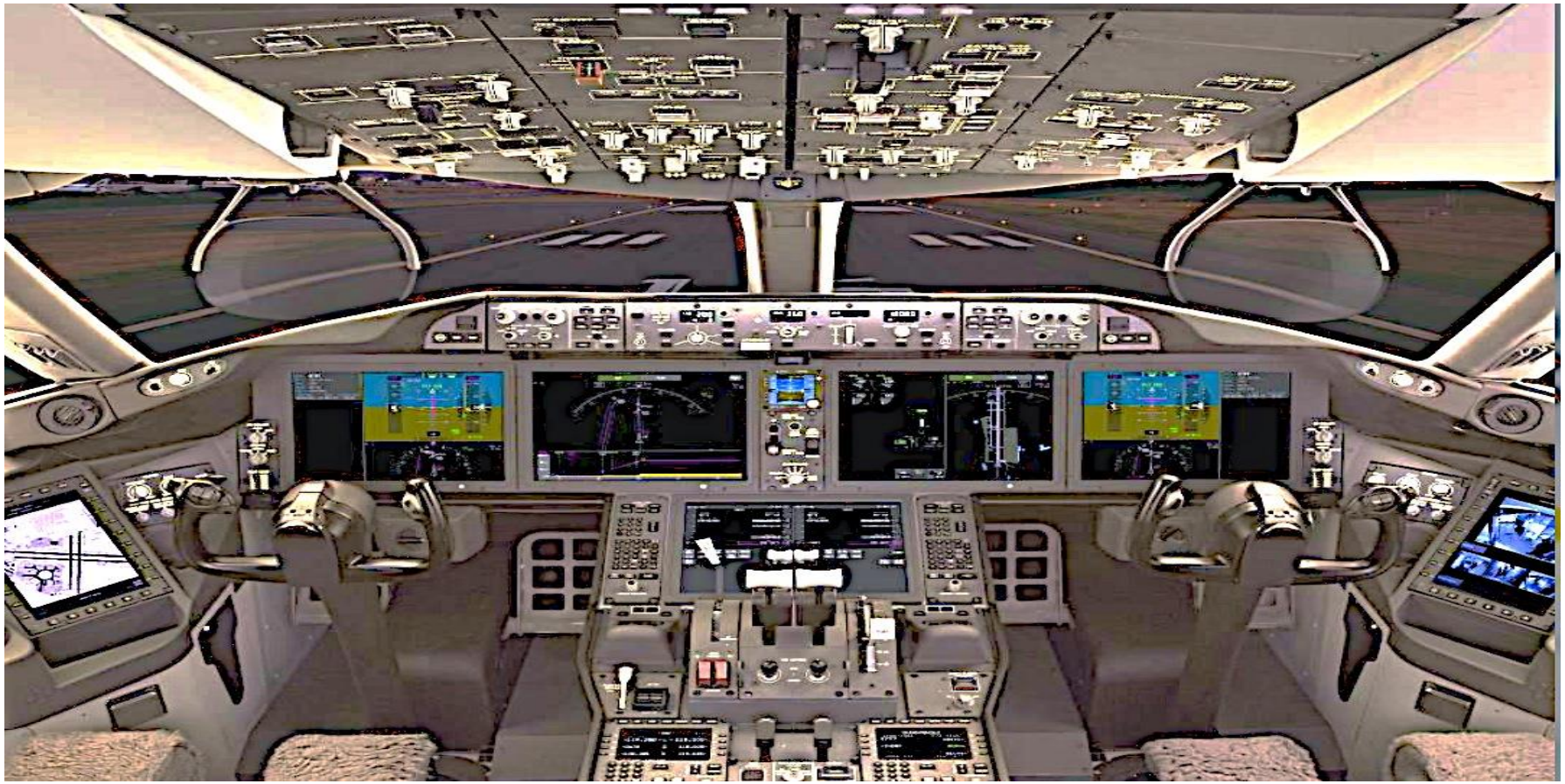
Economizing Aircraft and Operations

- Every modern aircraft is over budget and delayed

Airbus spent roughly $24 billion to develop the A380 aircraft. The plane was delayed for years because of manufacturing problems while Airbus struggled to keep the plane's weight down and coordinate the complex design among dozens of suppliers.

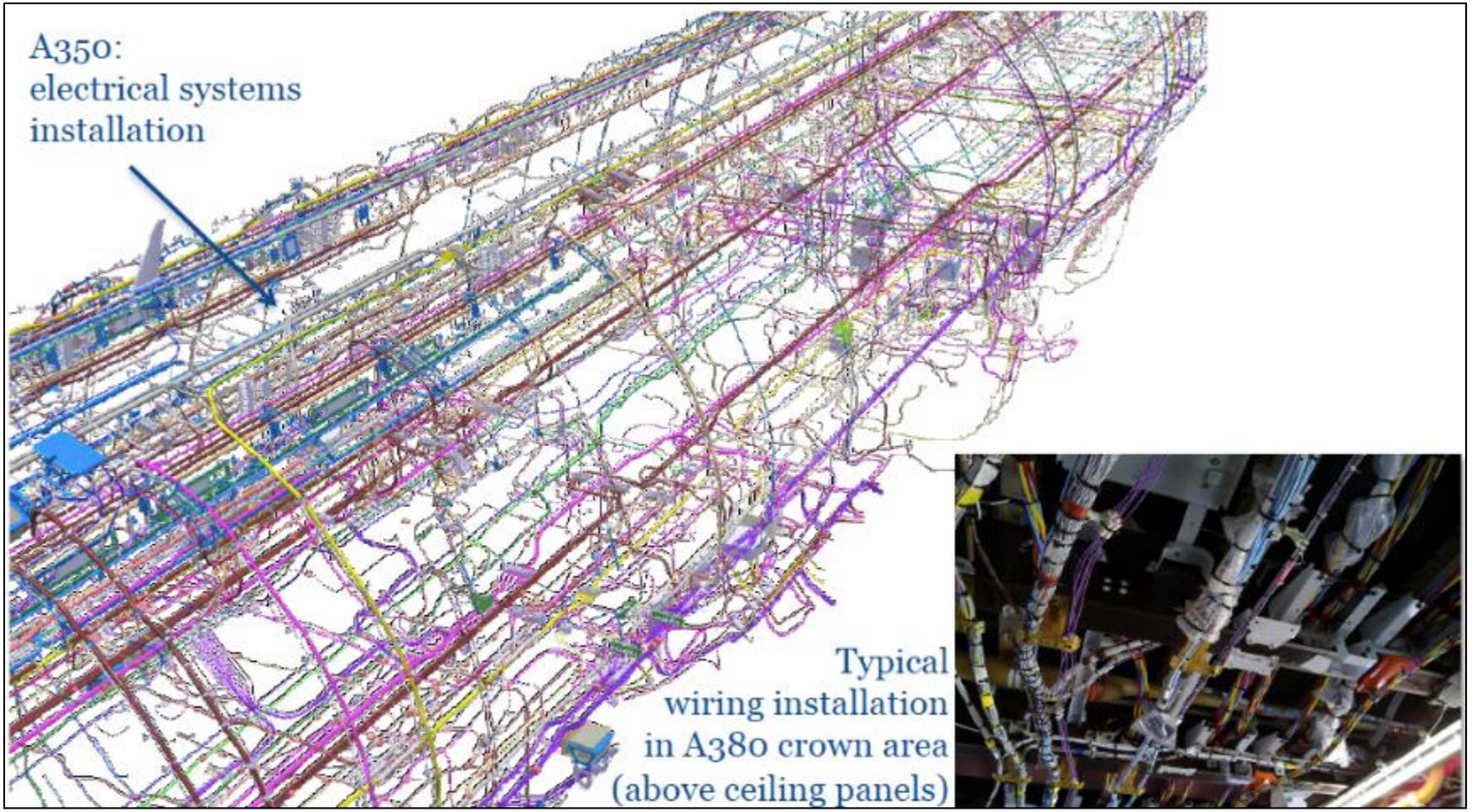
--New York Times, August 10, 2014

State of the Art



Boeing 787 many mechanical parts

Wiring



Complexity of Wiring: A380-800 has about 100,000 wires, 470 km, 5700 kg of weight, and additional 30% weight for harness to hold wiring

Strategy

- Reduce design complexity
- Reduce weight
- Reduce per aircraft software/hardware

- Increase software intensive controls and systems
- Reduce weight by software and wireless
- Promote cloud-based/networked functions
- Promote fleet optimization

Reduce overall aircraft design, assembly, maintenance, and operations cost

Examining AutoMax Concepts, Algorithms, and Technologies: SMART NAS

- Shadow Mode Assessment using Realistic Technologies for the National Airspace System (SMART NAS)
- Motivation
  - General agreement that National Airspace System needs to transform faster
  - NAS is a complex system with high safety requirements
  - Such incremental upgrade approach is rather slow and does not consider integrated operations efficiently
- Focused on longer-term concepts exploration and their interactions
  - Functional requirements, information flows, automation/human and air/ground allocations

SMART NAS needed to research and define AutoMax specifics

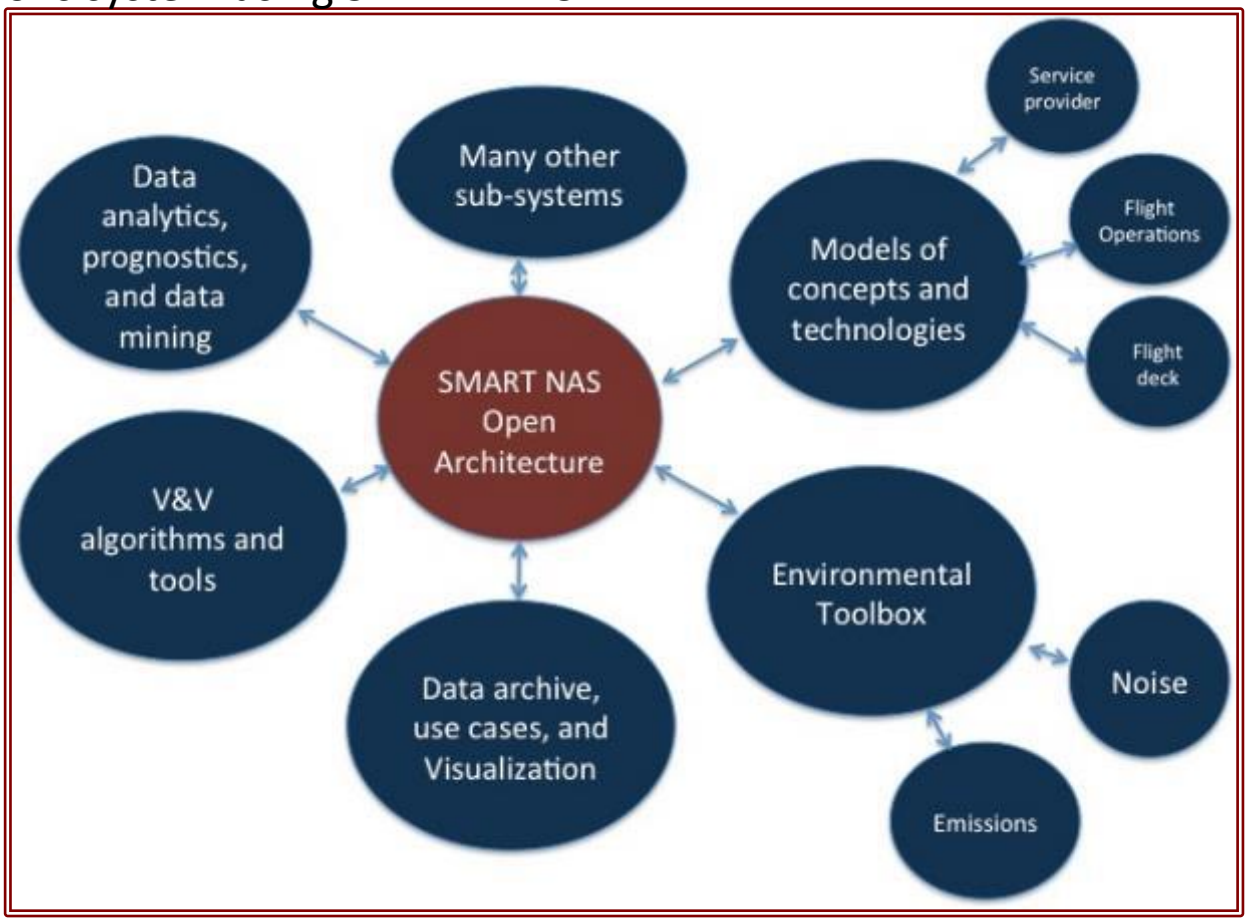
SMART NAS (continued)

- Objectives
  - Develop approach to faster validation of concepts, technologies and their integration, and future autonomy architectures
  - Reduce the time to validate concepts, technologies and their interactions
  - Provide plug-and-play capability that is modular and based on open architecture principles to compare alternative approaches
  - Provide real-time assessment of technologies as compared with current operations
  - Provide live, virtual, and constructive distributed environment
  - Provide multiple parallel universes
- SMART NAS capability is a community resource to reach transformed future

SMART NAS is a community resource to determine future functional architecture(s)

SMART NAS (continued)

- SMART NAS will allow examination of design alternatives, “auto” architectures, variety of roles of human-machine interface
- Open architecture based capability - Opportunity to redesign the airspace operations system using SMART NAS



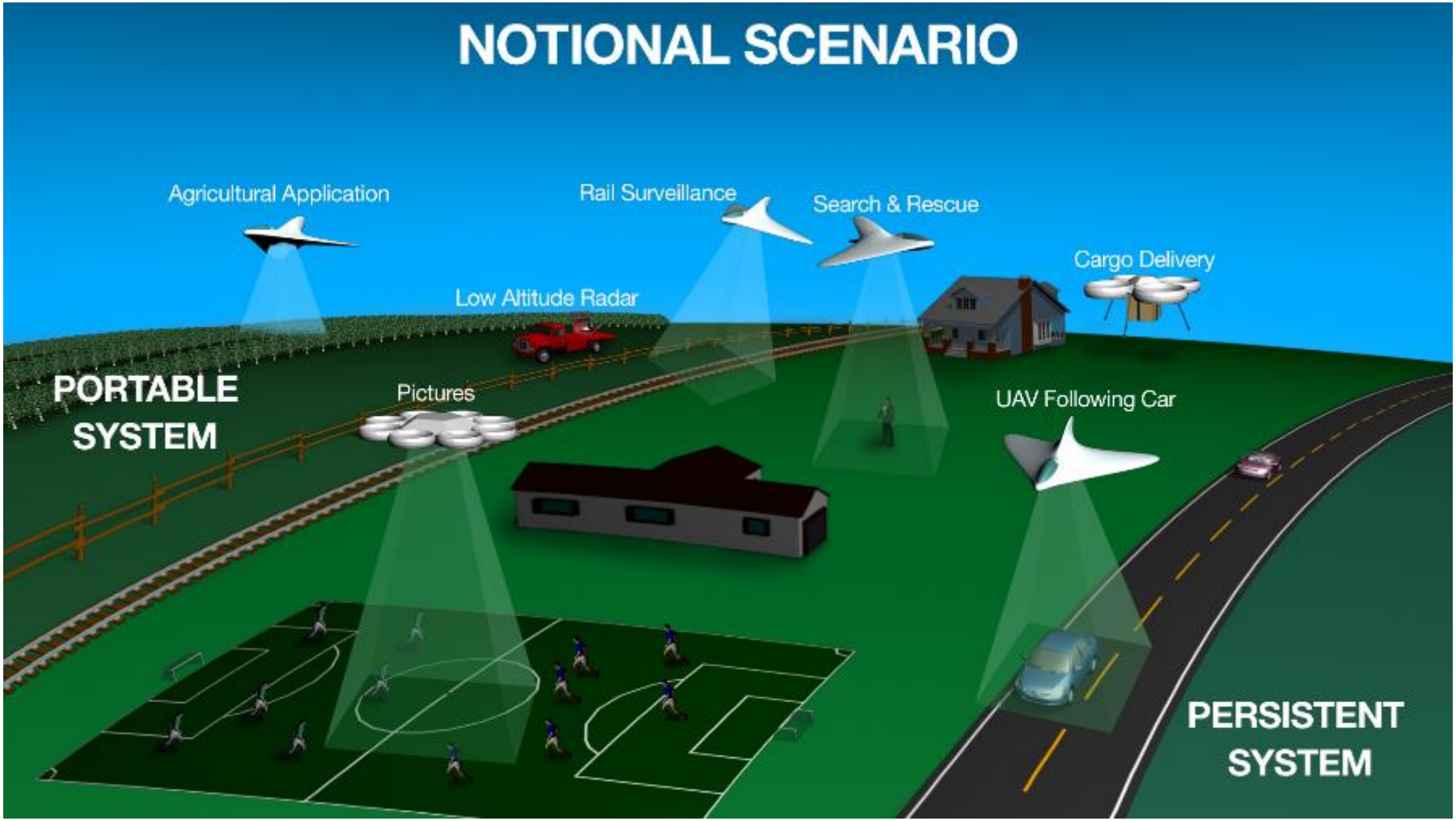
Examine future concepts, algorithms, architectures by live, virtual and constructive capability

Unmanned Aerial Systems Traffic Management (UTM)

- Many civilian applications of Unmanned Aerial System (UAS) are being considered
  - Humanitarian
  - Goods delivery
  - Agricultural services
  - Strategic assets surveillance (e.g., pipelines)
- Many UAS will operate at lower altitude (Class G, 2000 Feet)
  - Other low-altitude uses such as personal vehicles are emerging
- No infrastructure to safely support these operations is available
- Global interest (e.g., Australia, Japan, France, United Kingdom, Europe)
- Lesson from History: Air Traffic Management started after mid-air collision over Grand Canyon in 1956
- Need to have a system for civilian low-altitude airspace and UAS operations

UTM will enable low-altitude airspace operations

UTM Supported Applications



Heterogeneous vehicles and missions

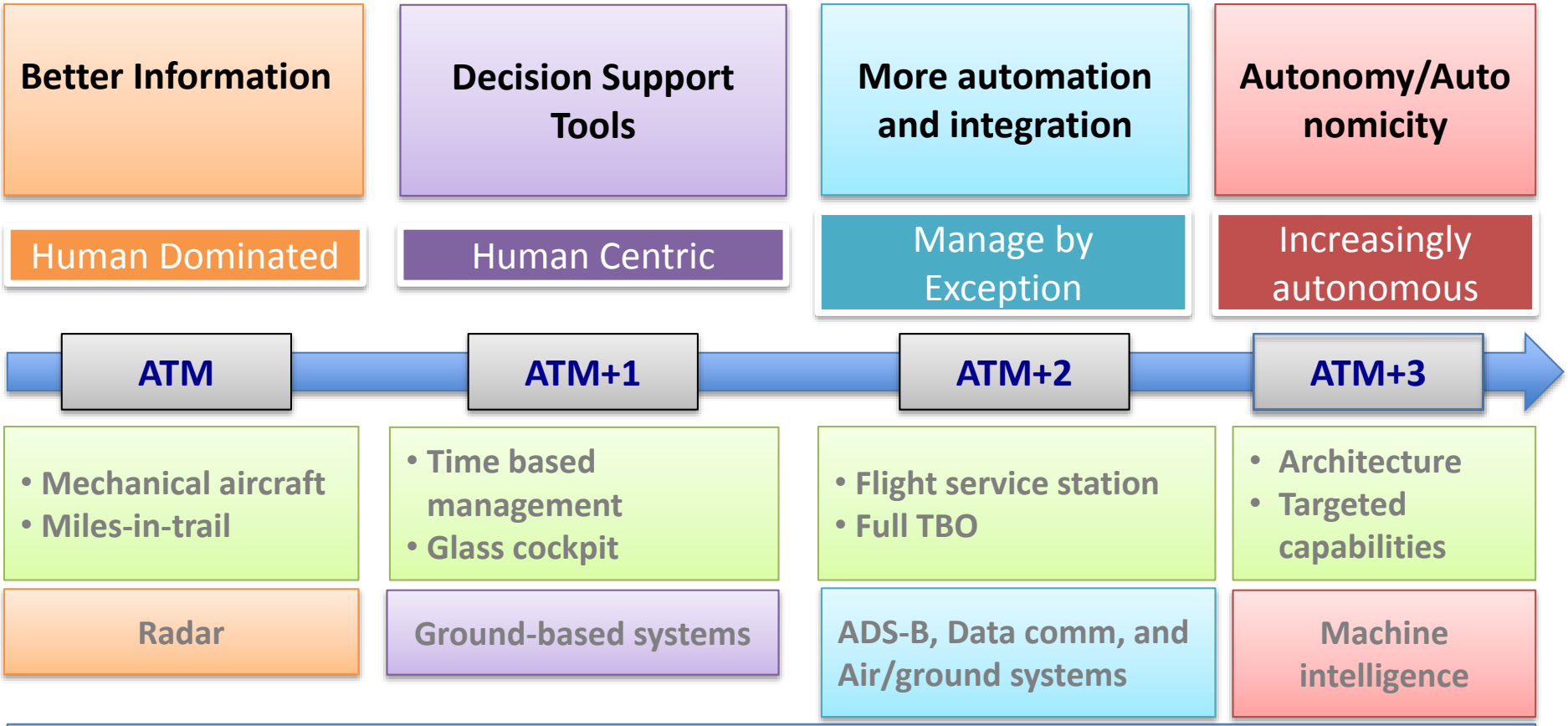
UTM Design Functionality

- UAS operations will be safer if a UTM system is available to support the functions associated with
  - Airspace management and geo-fencing (reduce risk of accidents, impact to other operations, and community concerns)
  - Weather and severe wind integration (avoid severe weather areas based on prediction)
  - Predict and manage congestion (mission safety)
  - Terrain and man-made objects database and avoidance
  - Maintain safe separation (mission safety and assurance of other assets)
  - Allow only authenticated operations (avoid unauthorized airspace use)

- Analogy: Self driving or person driving a car does not eliminate roads, traffic lights, and rules
- Missing: Infrastructure to support operations at lower altitudes

UTM functions will be similar to ATM but much more automated

Towards Autonomy



- Develop concepts, algorithms, technologies, and architecture(s) towards ATM+3
- Validate key "phase transition" technologies are feasible, safe and can be assured
- Analyze benefits and ensure overall autonomy architecture compatibility
- Fully develop, validate and migrate towards architecture that support safe autonomous operations
- Transition safe and beneficial technologies to stakeholders for operational use

Selected Challenges

- Affordable air transportation
- Environmentally friendly
- Increased mobility for goods, and people at faster speeds
- Enable future demand
- Sustainable and competitive
- Adequacy of machine intelligence for non-normal events
- Safe autonomous operations
- Safe last/first 50 feet operations of unmanned aerial systems under all conditions

Summary

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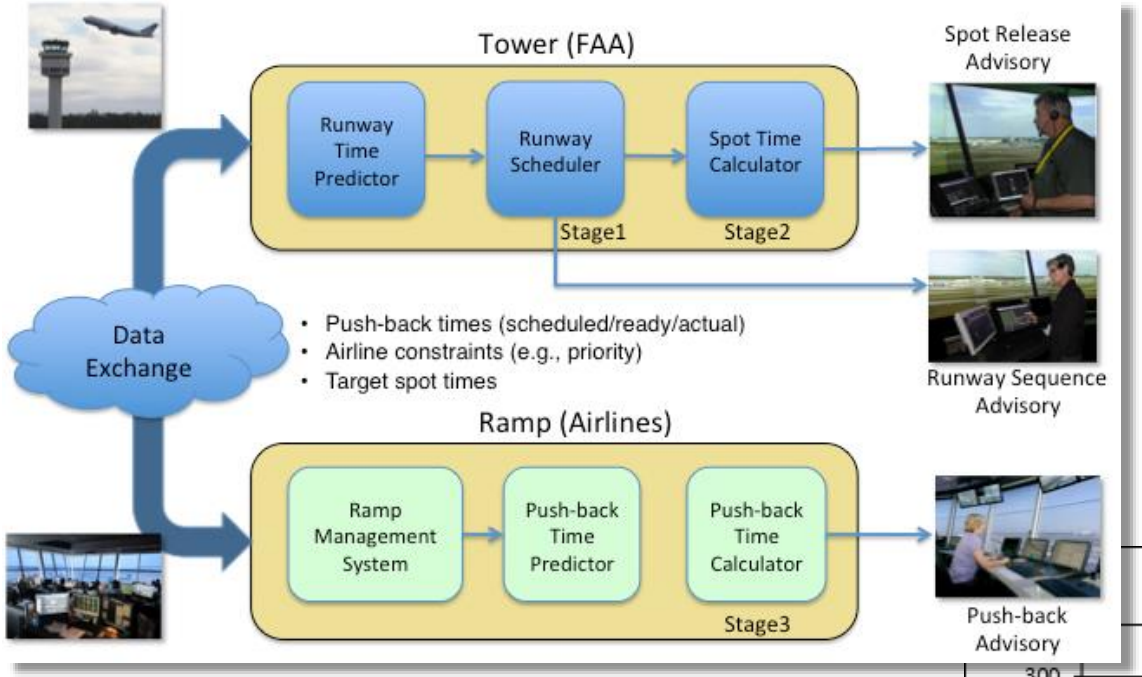
- National Airspace System is complex
- Many operational challenges
- NASA's discriminator: *Precision Scheduling and Delivery*
- Autonomy is needed
- Looking for collaborators: *We need you!*

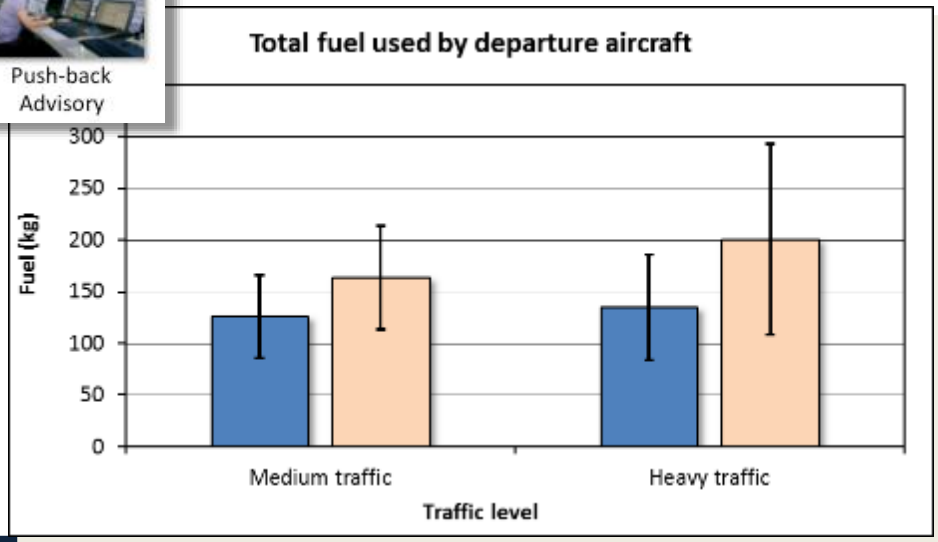
Metrics

- Scalability to accommodate future demand and vehicles
- Better on-time performance
- Better predictability of operations
- Increased system productivity
- Increased fuel efficiency
- Reduced environmental impact
- Maintain high throughput and capacity under all weather conditions
- Reduce total costs of operations

Surface Operations: Spot and Runway Departure Advisor

Increase surface operations efficiency

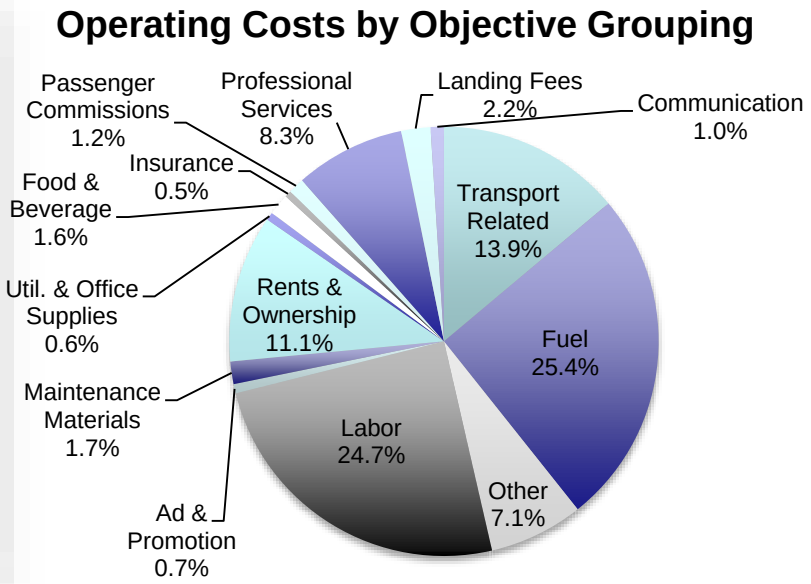




Separate User and FAA Decision Support Tools – offer direct benefit to users

AutoMax

Through the greatest use of autonomy, accommodate future demand, vehicle mix/airspace uses, increase efficiency and mobility, and different operating business models to enable highest possible realization of economic value from the airspace operations at the lowest possible total cost of operations



Winston Churchill – We have a great strategy, now let's see the results!

TC # 2: IADS- Pilot says, good morning I am ready to push off from the gate, controller says not so soon, expect delays. Then pilot says in that case we take back good morning..

TC# 3: Wx integration/- Bumpy ride, a pilot says "Oh no" on PA system. Then he realizes that the PA was on and says sorry folks, I spilled coffee on my pants and you should see front of my pants. The passenger says, you should see back of my pants.

TC # 4: Functional allocation -- Controller says – turn for noise abatement – we are at FL300. The controller says have you heard of the noise of two aircraft bumping into each other.

TC # 5: Oceanic

TC # 6: SMART NAS--SMART NAS – I have to speak slowly otherwise some folks think I am saying thing else instead of NAS?

TC # 7: TBO

TC # 8: Networked ATM: Tower says Delta 560 you have traffic at 10 am 6 miles, pilot says we have digital watches gives another hint.

TC # 9: Autonomy has a different meaning for me now that my daughter is 13.

Single Pilot Operations – "single" search

One day a radar controller did a mistake in sequencing the traffic for landing, he let a Boeing 747 as number 2 behind a Cessna 172, as it looks very weird, the B747 started to get closer to the Cessna, the controller instructed the captain of B747 to slow down 180 kts, captain did comply, after a while the controller instructed again the B747 to slow down to 160 knots, few moments later, the controller asked the captain of B747 to slow down to 130 kts! the captain asked the controller:

Capt: do you know at which speed does 747 stall?

contrl: I'm sorry...no idea...you can ask the co-pilot !

Woody Allen said – forever is a long time, particularly at the end.

Near-term UTM Builds Evolution

UTM Build	Capability Goal
UTM1	Mostly show information that will affect the UAS trajectories • Geo-fencing and airspace design • Open and close airspace decision based on the weather/wind forecast • Altitude Rules of the road for procedural separation • Basic scheduling of vehicle trajectories • Terrain/man-made objects database to verify obstruction-free initial trajectory
UTM2	Make dynamic adjustments and contingency management • All functionality from build 1 • Dynamically adjust availability of airspace • Demand/capacity imbalance prediction and adjustments to scheduling of UAS where the expected demand very high • Management of contingencies – lost link, inconsistent link, vehicle failure

Near-term UTM Builds Evolution

UTM Build	Capability Goal
UTM3	Manage separation/collision by vehicle and/or ground-based capabilities • All functionality from build 2 • Active monitoring of the trajectory conformance inside geo-fenced area and any dynamic adjustments • UTM web interface, which could be accessible by all other operators (e.g., helicopter, general aviation, etc.) • Management of separation of heterogeneous mix (e.g., prediction and management of conflicts based on predetermined separation standard)
UTM4	Manage large-scale contingencies • All functionality of build 3 • Management of large-scale contingencies such as “all-land” scenario

NASA Aeronautics Six Strategic Thrusts

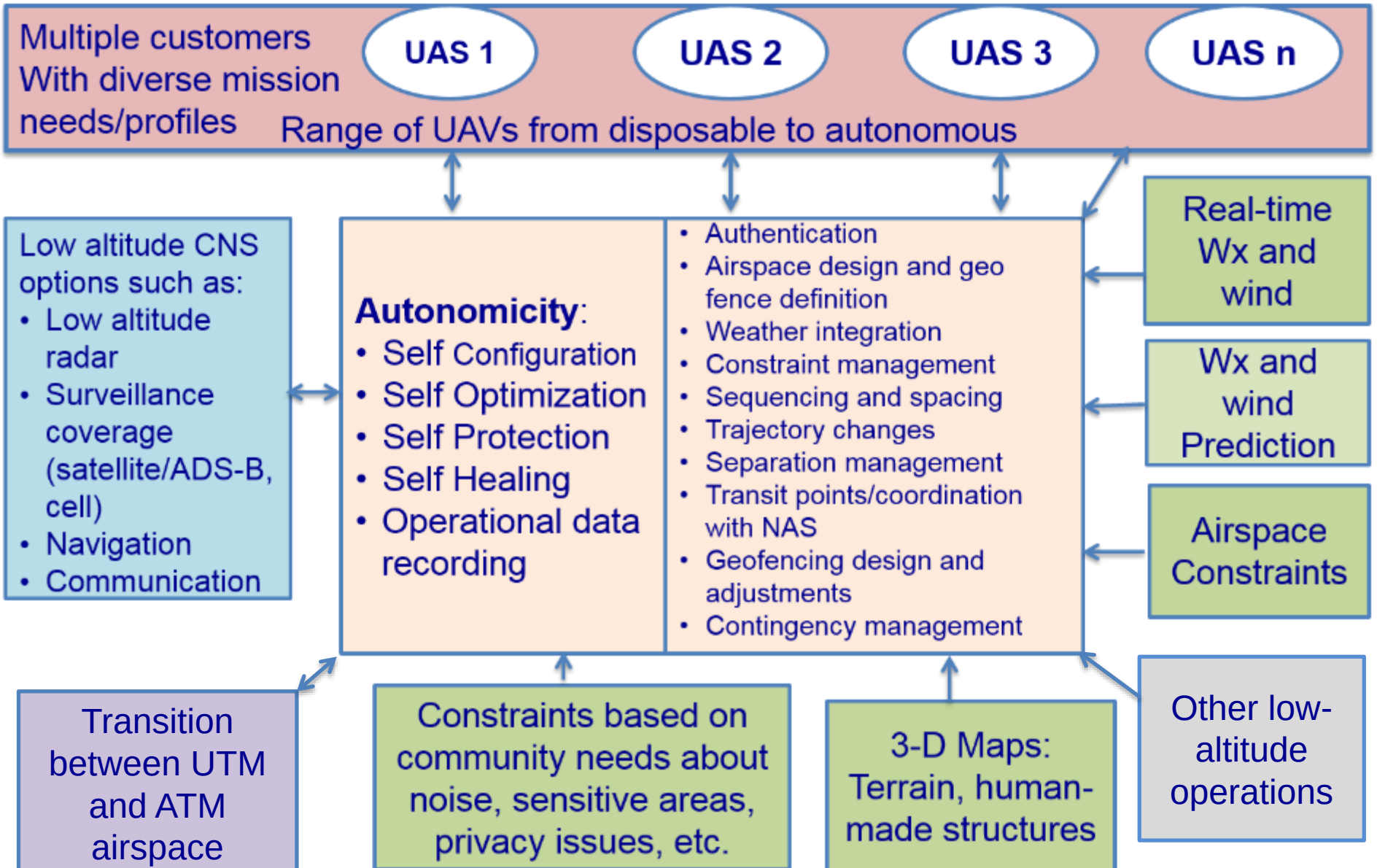
Safe, Efficient Growth in Global Operations
- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
- Achieve a low-boom standard

Ultra-Efficient Commercial Transports
- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance
- Achieve proactive safety management of the integrated aviation system

Assured Autonomy for Aviation Transformation
- Develop high impact aviation autonomy applications

UTM – One Design Option